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ABSTRACT

With the increasing adoption of handheld computers and their integration in our daily life, mobile computing is becoming an important component of existing computing environments. The new forms of interaction made possible by mobile computing pose new challenges for the design of pervasive computing environments aimed at seamlessly integrating heterogeneous devices. Among these devices, handheld computers provide mobile users access to information and awareness of opportunities for collaboration based on the context of the task at hand. Hospitals are working environments where information is distributed, workers are mobile and artifacts are used for coordination, which makes them convenient settings for the deployment of mobile and pervasive computing technology. Based on workplace studies conducted in a hospital, we designed and implemented a mobile collaborative system aimed at supporting opportunistic and distributed collaboration addressing issues of local mobility and allowing the seamless transfer of information among heterogeneous devices.

Keywords

Mobile computing, hospital work, heterogeneous devices

INTRODUCTION

Hospital staff is faced with working conditions that are substantially different from those of office workers, for which traditional desktop computers were developed. Hospital staff needs to move to locate colleagues, evaluate and care for patients, and access information and resources. Thus, mobility characterizes work in these environments. Also, physicians and nurses experience frequent interruptions and often need to change the context of their work based on their location, the patient they are currently attending, the notification of new lab results, and/or a sudden change in the state of a patient. These working conditions where people move between buildings or rooms in a local environment corresponds to what has been referred to as local mobility (Belloti and Bly, 1996). argue for the need to distinguish between local mobility and the more traditional notion of mobility, which typically takes place between remotely distributed collaborating groups (remote mobility). The needs for technological support vary greatly and are sometimes contradictory between these two modalities. This kind of local mobility poses new challenges for the design of computer support for mobility, and especially for user interaction.

Most hospital staff needs to move continuously around the premises to perform their daily work. They do this to access people, knowledge, and resources (Bardram and Bossen, 2003). For instance, physicians make daily rounds to evaluate and

diagnose patients, to find artifacts (patient records, x-ray images, medications) or locate specialists distributed in space or time. Thus, the hospital can be seen as an information space and it is by "navigating" this space that hospital's staff can get the information required to perform its work effectively (Bossen, 2002).

Hospital workers make decisions and act highly influenced by their location, that of those with whom they collaborate, and that of the artifacts, such as patient records or specialized equipment, required to perform their daily work (Munoz *et. al.*, 2003). Location, for instance, is useful to determine the type of information physicians and nurses might require. Physicians and nurses are also in frequent need to locate colleagues. A physician might require the opinion of a specialist to confirm a diagnosis; a nurse might need to contact the doctor in charge of a patient showing discomfort or pain; a resident physician might just need a couple of free hands to help with an intervention. These types of interactions have been referred to as casual, informal, or lightweight (Kraut *et al.* 1990; Whittaker 1995).

By lightweight interactions we mean the interactions that do not have a predefined schedule or place of encounter, are spontaneous, not planned and brief, and where the topic of the conversation can change during the course of the interaction. Lightweight interactions are often undervalued, yet, studies in office and educational environments show that these interactions play an important role in successful collaborative interactions (Contreras-Castillo 2004; Kraut 1996). This kind of interaction can be triggered by people, objects, actions or interactions (Wittaker, 1993; Kraut, 1993). Furthermore, informal interaction is grounded in awareness of the work environment such as the people, objects and activities (Gutwin, 2005). For instance, as physicians move within the hospital they walk down the halls, into patient rooms and public spaces engaging in casual encounters triggered by the location of a colleagues or the state of an artifacts such as the availability of laboratory results. This process of browsing the social environment helps hospital workers keep up-to-date with things going on with a substantial amount of information about the world in which they interact.

These challenges are motivating the widespread adoption of handheld computers in support of hospital work. It was estimated that about 40% of practicing physicians in the U.S. have and use Personal Digital Assistants (PDAs) in 2004, thus the overall percentage rate of consumer adoption has grown significantly (Chin, 2005). This trend has generated interest in the development of medical applications for PDAs (Fischer *et. al.*, 2003; Lapinsky *et. al.*, 2001).To date, the most popular handheld medical applications are ones that provide access to reference material, such as pharmacological databases (Lapinsky *et. al.,* 2004). PDAs wirelessly connected to a hospital information system can give physicians access to patient medical records from anywhere within the hospital. Furthermore, the complex characteristics of a hospital environment, motivates us to place special emphasis in supporting opportunistic and distributed collaboration. In this paper, we introduce a collaborative mobile application inspired by workplace studies conducted in a public hospital aimed at supporting these kinds of interactions among hospital workers.

The rest of this paper is organized in the following way. In Section 2 we briefly describe the results of a workplace study performed to understand the mobility experienced by hospital workers. In addition, this section presents one scenario derived from the study that guided the design of the system. In Section 3 we explain the architecture and design of the component-based mobile collaborative system. Section 4 illustrates the functionality of the system and the interactions of the architecture components. Finally, section 5 presents conclusions and directions for future work.

MOBILE COLLABORATION REQUIREMENTS IN HOSPITAL WORK

The characteristics of hospital work call for a new computing paradigm in which mobile support is of particular important. Because of this, we decided to understand how mobility is experienced by hospital workers to translate the way the work gets done into specific vignettes that capture facets of how mobile collaborative tools might fit into current work practices to ground our design.

Mobility in hospital work: A case study

We conducted a study aimed at revealing how much time hospital workers spend in different activities; how much they move, where they move to and why; with whom they collaborate more often and the artifacts they use in support of their work (Moran *et. al.*, 2005). This study was conducted for a period of five weeks, where two medical interns, two head nurses and two physicians were shadowed for two complete working shifts and interviewed by a couple of researchers. The main contribution of this study relies in the characterization of mobile work and the information usage practices that hospital workers engage in.

We found that individuals spent, on average, 59.92% of their time in their base location while the rest is spent on-the-move (40.08%). Even tough it is clear that hospital staff spends as much as half of their working shifts on-the-move; they do spend a considerable amount of time at what we have referred to as their base station. They need to do this in order to fill administrative forms, write medical notes or analyze medical evidence. Mobile computing devices, such as PDAs, are not

appropriate for many of these tasks, such as, writing relatively long documents or reading a medical article. Thus, the need to provide the environment with heterogeneous computing devices, ranging from handheld computers that can be used to capture and access limited amounts of information, to PCs that can be used at fixed sites for longer periods of time, and finally, semi-public displays located at convenient places, that can be used to share and discuss information with colleagues. Information transfer between these devices should be seamless, so as not to interrupt the natural execution of the task at hand.

Also, we observed that hospital workers have meaningful encounters and get work done while in the hallway. They spend almost 10% of their time in hallways. An important reason for this is that other hospital staff and patient relatives often see their presence in hallways as an opportunity to interact with them. Because of these, we refer to these hallways as an *"availability space"*, where frequent discussions and information exchanges take place. These opportunistic interactions are used among other things to hand physicians a form to sign, ask about the status of a patient, or discuss a clinical decision. Many of these interactions involve the exchange of documents and/or their analysis. Research in CSCW has been conducted towards supporting this type of interaction in office environments through computer-mediated communication (Isaacs, 1996; Kraut *et. al.*, 1990; Whittaker, 1995). These solutions are clearly not appropriate for a hospital environment, where according to our data; workers spend only a fraction of their work shift in front of a computer, and more than twice this amount of time away from their base station. Indeed, what is required is support for impromptu face-to-face encounters.

These characteristics have suggested us to envision a mobile collaborative system that supports opportunistic and distributed collaboration with the ability of detecting the presence of another device in the vicinity, as well as, allowing users to be aware of the location of colleagues, sharing information between heterogeneous devices, remotely monitoring other computers, and sharing handheld applications.

Scenarios

From our understanding of how work gets done in a hospital, we identified real use scenarios aimed at simplifying complex tasks through the use of mobile computing technology. To present our vision of how mobile collaboration technology can empower medical staff in support of their everyday activities we describe one of such scenarios:

Supporting opportunistic interactions through application sharing and remote control of information

This scenario illustrates how the system makes use of the user's position to provide location awareness, support application sharing through proximity-based location and remotely control other devices.

When Rita, a medical intern, is evaluating the patient in bed 222, she notices that he is not responding well to his medication. After reviewing the patient's medical record in her handheld she realizes through the location application in her PDA that Dr. Diaz, the attending physician, is walking down the corridor –which is close to her position-. She decides to get a hold of him in the hallway to discuss with him the patient's reaction to the medicine. While Rita and Dr. Diaz discuss the case in the hallway, they decide to simultaneously consult the patient's medical record. Using the application-sharing tool they synchronize their PDA's to share the information both consult while discussing the medical case. In this system, the devices in the vicinity of Rita's PDA are used to select the target device to establish application sharing by proximity. Once the users are sharing the application, Dr. Diaz using the control remote tool, accesses his office's computer to retrieve recent journal papers related to the medication and the patient's condition. Dr. Díaz selects an article that describes different administration doses for certain medications to discuss with Rita. While Dr. Diaz uses his handheld to highlight some information relevant to the patient's diagnosis; Rita, visualizes the information marked by Dr. Diaz in her PDA. Based on the evidence discussed they decided to change the dose administrated to the patient.

THE LOCATION-AWARE MOBILE COLLABORATIVE SYSTEM

Motivated by the nature of hospital work, we designed and implemented a mobile collaborative system aimed at supporting co-located opportunistic interactions, proximity-based information transfer and sharing, and control of remote devices. These services are aimed at providing hospital staff with awareness information, as well as application and information sharing services, in the highly mobile working environment in which they work.

Architecture

Figure 1 shows the architecture of the component-based system using a client-server architecture as a basis for its implementation. Wireless connectivity between servers and mobile clients is achieved through 802.11b access points. The system includes eight agents, four on the client and two in a server. We implemented two versions of these agents: one for PDAs using Windows Mobile on the top of mSALSA and another for desktop computers (PC, laptops, public displays) using Windows XP on top of SALSA (Rodriguez *et. al.*, 2005).

In our architecture the *agent Broker* handles communication between agents through XML (eXtensible Markup Language) messages storing the state of agents and notifying their changes to other agents subscribed to them. The *Location Estimation agent (LE-a)* determines the approximate location of users and devices within a hospital. Through this component the proximity based functionality is provided. The *Migration component* allows the seamless transfer of information among heterogeneous devices. This component uses the *Source Proxy agent (SP-a)* and the *Information adaptation agent (IA-a)*, which reside in the client application and communicate through the broker with the *Target Proxy Agent* (TP-a); which acts as a server and must be located in the target device. Finally, the *Controller* component is used for proximity-based application sharing and remote control of computing devices. This component is formed by a *Controller agent (C-a)* which resides in the source device and the *Echo server agent (ES-a)* that resides in the target device. Finally, the *Context-aware privacy client and the Context-aware privacy agent* act as a filter between the client applications and the broker to ensure user's privacy.

Thus, five main services are provided through these components in support for mobile collaboration. The first service provides location awareness of users. Based on this information a user can decide to initiate a lightweight interaction with another colleague, as described in the scenario where Rita gets a hold of Dr. Diaz in the hallway. A second service allows the seamless transfer of information among heterogeneous devices. For example, a physician might need to transfer from his PDA to the public display a recent article to enrich a discussion. The third service allows physicians to share with colleagues the information they visualize in their PDAs, and the control of the applications that display this information, as we show in the scenario, when Rita and Dr. Diaz share the information that both see on their PDA. The fourth service allows physicians to remotely control remote devices, as illustrated in the scenario when Dr. Díaz controls his computer retrieving journal papers. The final service allows the users to specify privacy policies to protect their privacy, as well as, provides feedback, In both cases, the user could be able to change their policies based on his needs. In the following lines we described how the components work to support the services just described.
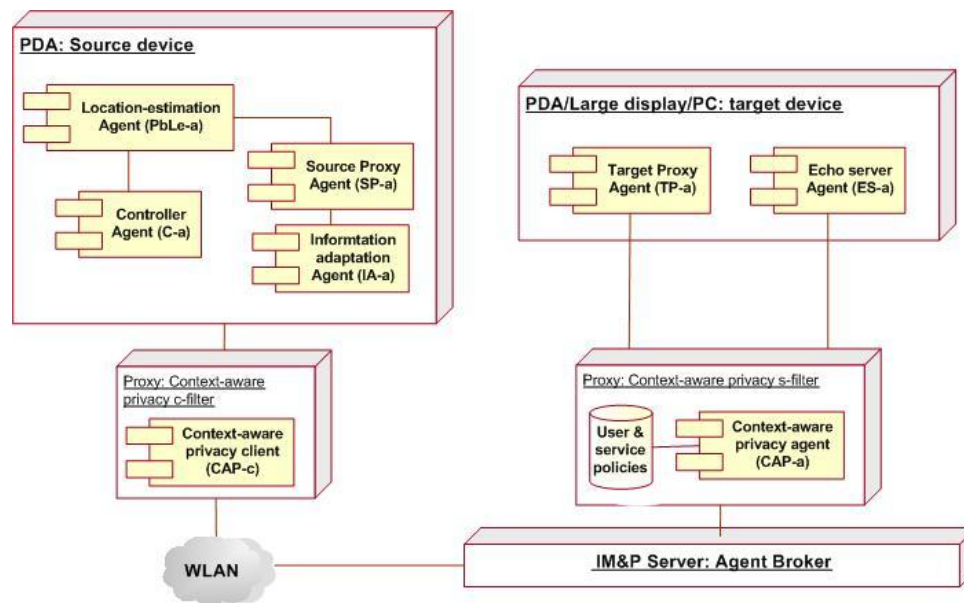

Figure 1 Architecture of the mobile collaborative system

Ensuring personal and information privacy

Privacy is an important issue when users share information, particularly in a hospital environment. For this reason we placed special emphasis on protecting the users' privacy by allowing the control of the information and providing feedback about how it's used (Bellotti and Sellen, 1993). Within the context of this application, we identified that the persistence of the information, the identity of the sender and how the information is displayed must be managed to protect privacy. For example, during a meeting, a user might need to transfer a document from his PDA to a public display. In this case, he would like to share the information with the participants until the meeting ends and he might not want to automatically display the information for privacy concerns. Also, there is a tradeoff between the amount of privacy a user is willing to concede and the value of the services that can be provided by the application (Jiang and Landay, 2004). For instance, if a physician doesn't want to be easily located or interrupted he can login into the hospital information system sharing only his role as a physician,

and not his identity. Therefore, users should be able to control the precision with which their location is made available to others, based on contextual variables such as the identity of the receiver.

To ensure user's privacy we designed a privacy layer that takes the user's context to adapt the services provide by the application satisfying a certain level of Quality of Privacy (QoP), that both, the application and the user have agreed upon (Tentori *et. al.* 2005). This layer lies between the application and the broker, and is implemented with two agents. The *Context-aware privacy client* allows users to negotiate with the application a certain level of QoP which is mapped into a set of privacy policies acting as a filter between the users and the application. On the other hand, the *Context-aware privacy agent* acts as a filter between the application and the user. Thus, each time an agent (i.e. echo server) requires information of the users connected to the system, this filter evaluates the need of privacy and based on this evaluation decides to admit or reject the request. If the request is accepted users' policies must be applied adapting the users' information. These agents manage Stanza Security ensuring confidentiality and integrity of the information transmitted between endpoints (Karneges, 1999) secured into an OpenPGP format (Callas *et. al.* 1998).

Location awareness for opportunistic interactions

To address our vision, we will have to keep in mind that the system should be able to support improvised meetings in different places. In this case, location awareness can be a trigger for opportunistic meeting situations. For example, a physician might need to collaborate in a hallway to discuss a particular clinical case as the scenario shows.

To introduce location awareness we use a location estimation component that estimates the position of users within a hospital (Castro and Favela, 2005). Radiofrequency (RF) signals received by a mobile device carried by medical staff from at least three access points are measured to obtain their signal strength. A trained backpropagation neural network is embedded within the component and is used to estimate the approximate location of the users. Neural networks can learn from training examples and map input sequences (signal strength) to output sequences (2D coordinates). In addition to signal strength, we make use of neighbors surrounding the location to be estimated. This simulates the use of previous time instant guesses to reduce the location estimation error and alleviate the hopping trajectories of users. In this way, the network takes into account information from the past to reduce the error which is diminished by almost 55% when using this approach. This component was trained and tested with data from the internal medicine area of the hospital. Several paths followed by medical staff within that area were covered in order to test our approach.

Figure 2 shows a screenshot of the application designed to estimate the location. Paths are drawn to observe the changes in the estimation. However, in the real working application only the last estimation is displayed.

Figure 2 The handheld location estimation application

Seamless information transfer among heterogeneous devices

The idea of seamless information transfer consists in allowing users to transfer information to any device in the vicinity, such as a PDA, a PC or a public display, from a handheld computer. To provide this functionality we designed and implemented a migration component that allows the transfer of information among heterogeneous devices (Amaya *et. al.*, 2005). The information to be transferred includes digital files and URLs, while the source and target devices could include PDAs, PCs and public displays.

The component is implemented with four agents. The *Source Proxy agent* represents the information to be transferred by the user to another device, the mechanisms required to transfer the information and the permissions granted by the source device. The *Information Adaptation agent* adjusts the information based on the characteristics of the target device and the specifications defined by the source device. For instance, medical images being moved to a PDA might be reduced in size before being transferred. Finally, the *Target Proxy agent* represents: characteristics of the target device; the device itself

which will decide whether to accept or reject the transfer request; and the actions to be performed with the information received, which could include, storing or opening the file with a specific application.

The command is activated from the file system by using a selection in the option menu displayed with a right-click or triggered from another application that whishes to invoke this service. For instance, URL's can be transferred by directly clicking the URL on the Web browser. Once the menu appears, the user needs to select the *Transfer To...* option as Figure 3 illustrates. When selecting this option, a list of target devices in the vicinity is displayed. The information migration takes place when the user chooses a target device. Once the information has been transferred, a notification is sent to the source device and the file is opened by an application in the target device, according to its filetype.
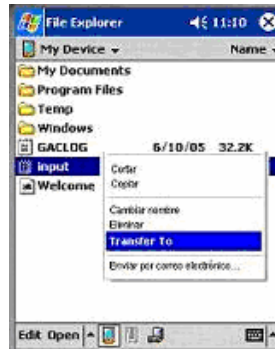

Figure 3 Screenshot illustrating the selection of a file to be transferred

Proximity-based application sharing

The idea of proximity-based application sharing consists of displaying the screen of any device in the vicinity, such as a PDA, a PC or a public display, on a handheld computer, and being able to remotely share the control of the device with its owner and/or other users. The application-sharing component is based on a client-server architecture, where the client is the controller device and the server is the device to be controlled. The server, which is called the echo server, launches a worker thread for each client connection and broadcasts a full resolution image of the screen to all the clients. To be precise, the server echoes the screen of the controlled device on the controller device. The architecture can be observed in figure 4.

Proximity-based sharing allows the user to take control of any device within a given area. Interaction among several users might be desirable on devices such as public displays, while screen sharing among PDA's might be adequate for one-to-one user interaction. PDA screen sharing consists of displaying the screen of one mobile device in another handheld. This is done to support on-the-move collaboration without the need of a public display. The location estimation component is used to detect the devices that are close to the handheld interested in establishing an application sharing session. Once the user chooses a device, a session is established if the device has been configured to allow for open application sharing, as might be the case for a public display, or else, an invitation to join a session is sent to the user of the device that was selected. Once a session is established, both users can control the PDA being shared. The owner of the device being shared has a priority for floor control.
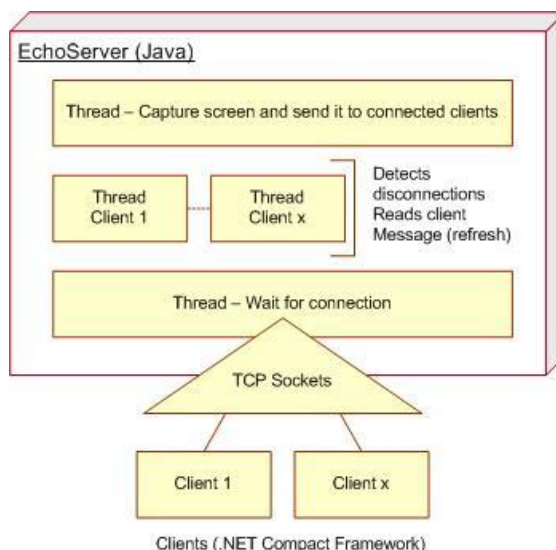
Figure 4 Proximity-based application sharing component

Meeting support through the interaction of public displays and handheld computers

Impromptu or planned meetings can be supported by allowing a group of physicians to remotely control a public display with their handhelds. In this case the controller component uses the echo server to control the mouse of a device with a PDA. The component should be capable of handling concurrent controllers but only one at a time using the echo server. The user that has control of the floor is able to move the cursor as well as type on the device being controlled, while the other users are only able to point at the screen using a telepointer. Figure 5 illustrates how hospital workers could collaborate through a large display using their PDAs.

Figure 5 Remote control of a large display. (a) A physician interacts with a public display while a colleague remotely interacts with the public display from his PDA. (b) A close up of the PDA's remote control application.

Figure 6 shows a screenshot of the application illustrating the remote control of a large display from a PDA. The user's PDA displays the same information projected on the large display. Such information can be displayed in different ways, for this the user makes use of the tool bar (figure 6c) provided by the component. The MiniView tool (figure 6a) provides a full, small depiction of the large display where, if desired, the user can draw a box to zoom on a specific area of the screen. Figure 6b shows supplementary tools used to improve the usability of the component: magnifier buttons to zoom in and out the image and a directional pad to control the speed of the cursor.

Figure 6 Screenshot illustrating the remote control functionality. (a) The MiniView tool; (b) The directional pad used to control the speed of the cursor; (c) Options of the remote control application

SAMPLE APPLICATION

Figure 7 illustrates a sequence diagram showing how the system's components interact to support the scenario discussed above. As Rita, a medical intern, moves around the patients' rooms, the location estimation agent estimates her position and notifies this information to her fellow hospital workers in the area. Location information is displayed on a floor map as illustrated in Figure 4. Using this information, Rita decides to interact with Dr. Diaz, the attending physician, to discuss the evolution of the patient in bed 222. While Rita interacts with Dr. Diaz, she decides to share the patient's medical record currently displayed on her PDA. In this case, Rita's handheld computer (source handheld computer) sends a request to create a hierarchical meeting through the Controller agent of this device (Source controller agent). The source controller agent requests to the Echo server agent a telepointer to update the UI and start a sampled thread. The source controller agent sends a message to the source handheld computer to notify the acceptance of the request. After that, the source controller agent requests the location estimation agent the list of devices in the vicinity of Rita's handheld to create an ad-hoc network connection based on their proximity. Using this network, Dr. Diaz' handheld is identified as the target device with which an application sharing session will be established. The target handheld joins the meeting through the target controller agent. Finally, the echo server assigns a telepointer to the target controller agent to update the UI and start a sampled thread.
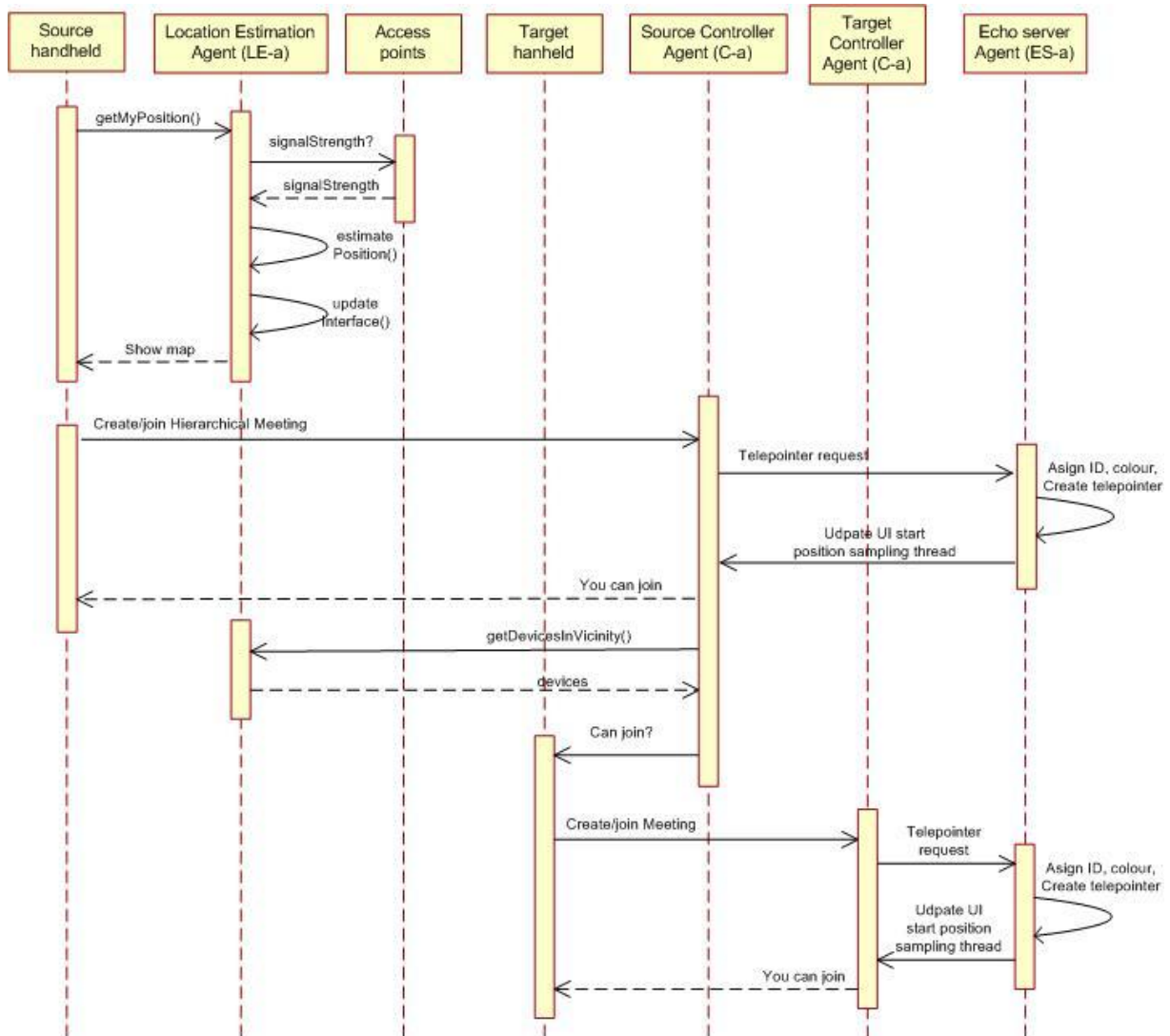
Figure 7 Sequence diagram showing the interactions of the components

CONCLUSIONS

Hospitals are complex work environments where people and information are distributed, thus demanding considerable coordination and communication among the professionals that work in such settings. Hospital information systems that provide access to electronic patient records are a step in the direction of providing accurate and timely information to hospital staff in support of adequate decision-making. This has motivated the introduction of mobile computing technology in hospitals based on designs which respond to their particular conditions and demands.

Among those conditions is the fact that hospital workers interact frequently while on-the-move. Indeed, the variety of areas of expertise involved in patient treatment, as well as the frequent information exchanges, trigger essential coordination and collaboration issues. In the paper, we present a set of services available through a handheld computer to support mobile workers' collaboration in local mobility settings. We propose to assist hospital workers' formal and informal interactions by integrating heterogeneous devices such as public displays and handhelds. We designed and implemented a system that creates collaborative environments on-the-move, around a public display or with other mobile devices. To provide this functionality, the system allows the user to be aware of the presence and location of fellow hospital workers, seamless transfer of information between heterogeneous devices, and being able to collaboratively control and share the display of another computer in the vicinity. Our attention focused on offering wireless concurrent control and pointing capabilities with a pleasant user experience.

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